IMPROVED PROCEDURES FOR DETECTING SEISMIC SOURCE DEPTHS FROM DEPTH PHASE INFORMATION

QUARTERLY REPORT

Edward A. Page

February 1976

Sponsored by:

Advanced Research Project Agency
ARPA Order No. 2251

DEPARTMENT OF DEFENSE FORMS

F-200.1473 *DD Form 1473:* Report Documentation Page

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 Improved Procedures for Determining Seismic Source Depths from Depth Phase Information.		5. TYPE OF REPORT & PERIOD COVERED Quarterly Report, 1 Dec 75-29 Feb 76
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Edward/Page		8. CONTRACT OR GRANT NUMBER(s) 15 F08606-76-C-0003
9. PERFORMING ORGANIZATION NAME AND ADDRESS ENSCO, Inc., 8001 Forbes Pl., Springfield, Va. 22151		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS ARPA Order-2551
11. CONTROLLING OFFICE NAME AND ADDRESS DCASD Baltimore, 300 E. Joppa Road, Rm. 200, Towson, Md. 21204		12. REPORT DATE 11 Feb 1976
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) VELA Seismological Center 312 Montgomery St., Alexandria, Va. 22314		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

12 17p. 16 VT/6710

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Seismic source depth, depth phase, echo detection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Seismic source depth determination techniques, developed under two previous contracts, were formulated into an automated analysis procedure. Differential travel time information, for several propagation modes relevant to the analysis, have been made accessible through 3-D curve fitting.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

406 167 LB

SUBJECT: Improved Procedures for Determining Seismic Source Depths from Depth Phase Information

AFTAC Project No.	VELA T/6710
ARPA Order No.	2551
ARPA Program Code No.	6F10
Name of Contractor	ENSCO, INC.
Contract No.	F08606-76-C-0003
Effective Date of Contract	September 1, 1975
Reporting Period	December 1, 1975 February 29, 1976
Amount of Contract	$59,998
Contract Expiration Date	June 30, 1976
Project Scientist	Edward Page 703/321-9000

Introduction and Summary

During the second quarter of this contract the automated seismic source depth analysis procedure was further developed and applied to seismic data. This analysis was focused on determining whether the use of the later seismic phases significantly contributed to the ability to obtain depth determinations. It was demonstrated that this analysis procedure does make constructive use of the depth phase information contained throughout the coda. This ability to utilize this additional depth phase information will enable source depth determination for events having poorer signal/noise ratios and/or recorded at fewer stations, than is previously possible.

The Illinois Event of November 9, 1968 was analyzed to produce depth estimates using different portions of the coda and using depth phase information arriving from individual seismic phases (P, PP, PPP or PcP). The success of these results as well as correct depth estimates obtained using individual stations for which previous cepstrum analysis was ineffective, indicates the potential of the depth determination analysis procedure. We now discuss these results in more detail.

Major Accomplishments

The seismic source depth determination procedure flow chart in Figure 1 has been further applied to the Illinois Event for the purpose of determining whether the depth phase information contained in the later seismic phase is significantly enhancing ones ability to extract seismic source depths. In Figure 2 is a portion of the

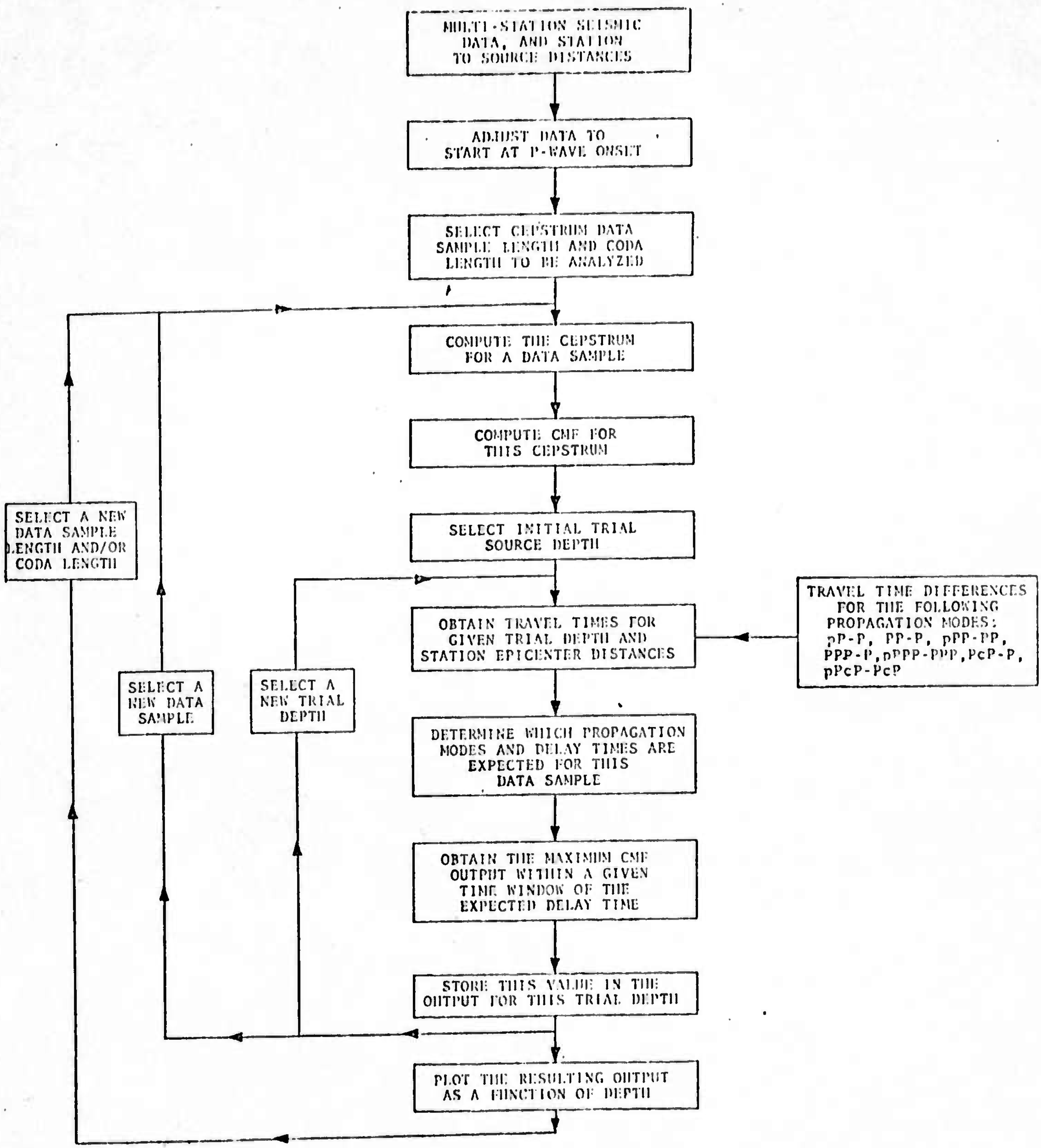

MULTI-STATION SEISMIC DATA, AND STATION TO SOURCE DISTANCES
ADJUST DATA TO START AT P-WAVE ONSET
SELECT CEPSTRUM DATA SAMPLE LENGTH AND CODA LENGTH TO BE ANALYZED
COMPUTE THE CEPSTRUM FOR A DATA SAMPLE
COMPUTE CMF FOR THIS CEPSTRUM
SELECT INITIAL TRIAL SOURCE DEPTH
OBTAIN TRAVEL TIMES FOR GIVEN TRIAL DEPTH AND STATION EPICENTER DISTANCES
TRAVEL TIME DIFFERENCES FOR THE FOLLOWING PROPAGATION MODES: pP-P, PP-P, pPP-PP, PPP-P, pPPP-PPP, PcP-P, pPcP-PcP
DETERMINE WHICH PROPAGATION MODES AND DELAY TIMES ARE EXPECTED FOR THIS DATA SAMPLE
OBTAIN THE MAXIMUM CMF OUTPUT WITHIN A GIVEN TIME WINDOW OF THE EXPECTED DELAY TIME
STORE THIS VALUE IN THE OUTPUT FOR THIS TRIAL DEPTH
PLOT THE RESULTING OUTPUT AS A FUNCTION OF DEPTH
SELECT A NEW TRIAL DEPTH
SELECT A NEW DATA SAMPLE
SELECT A NEW DATA SAMPLE LENGTH AND/OR CODA LENGTH

Figure 1

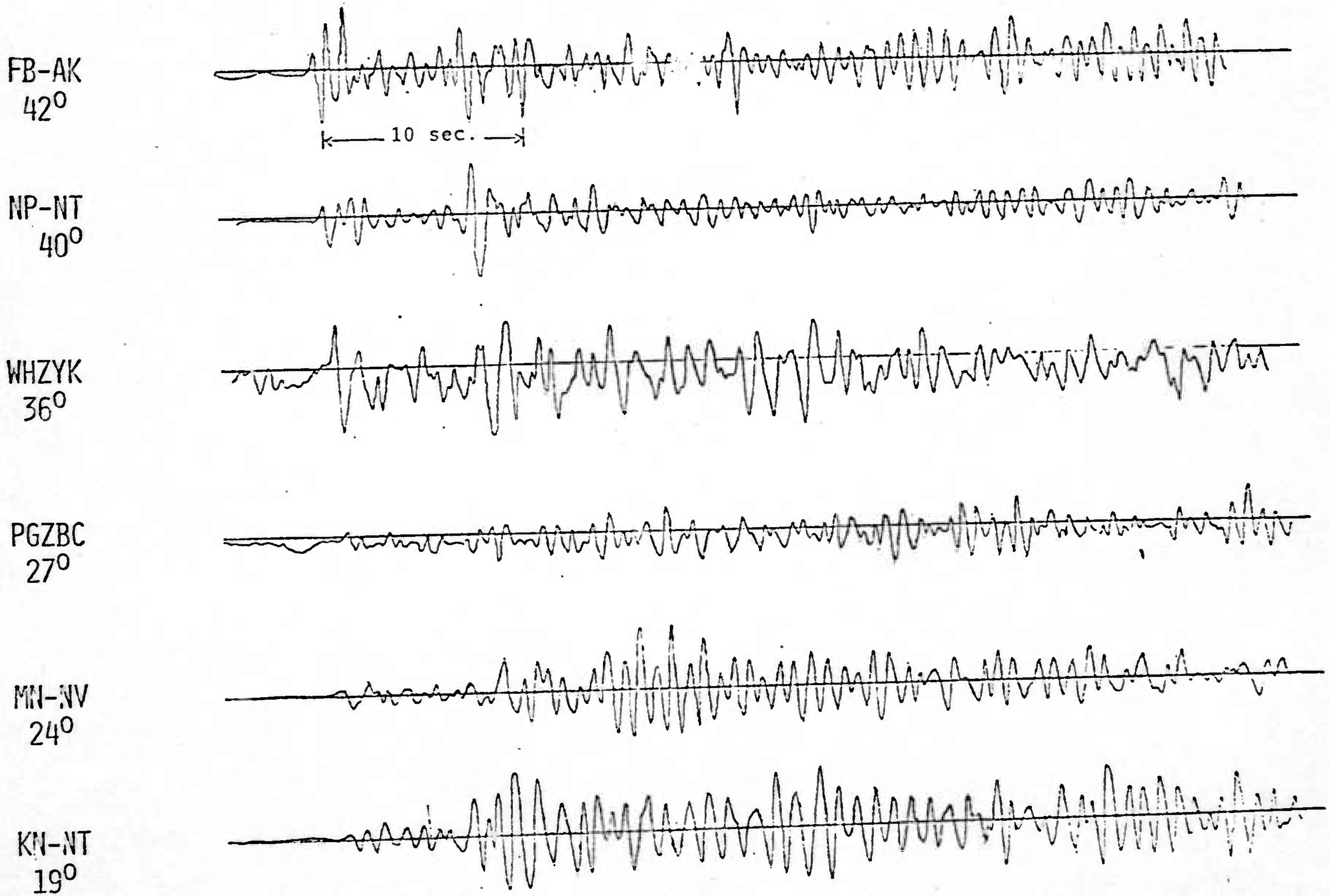
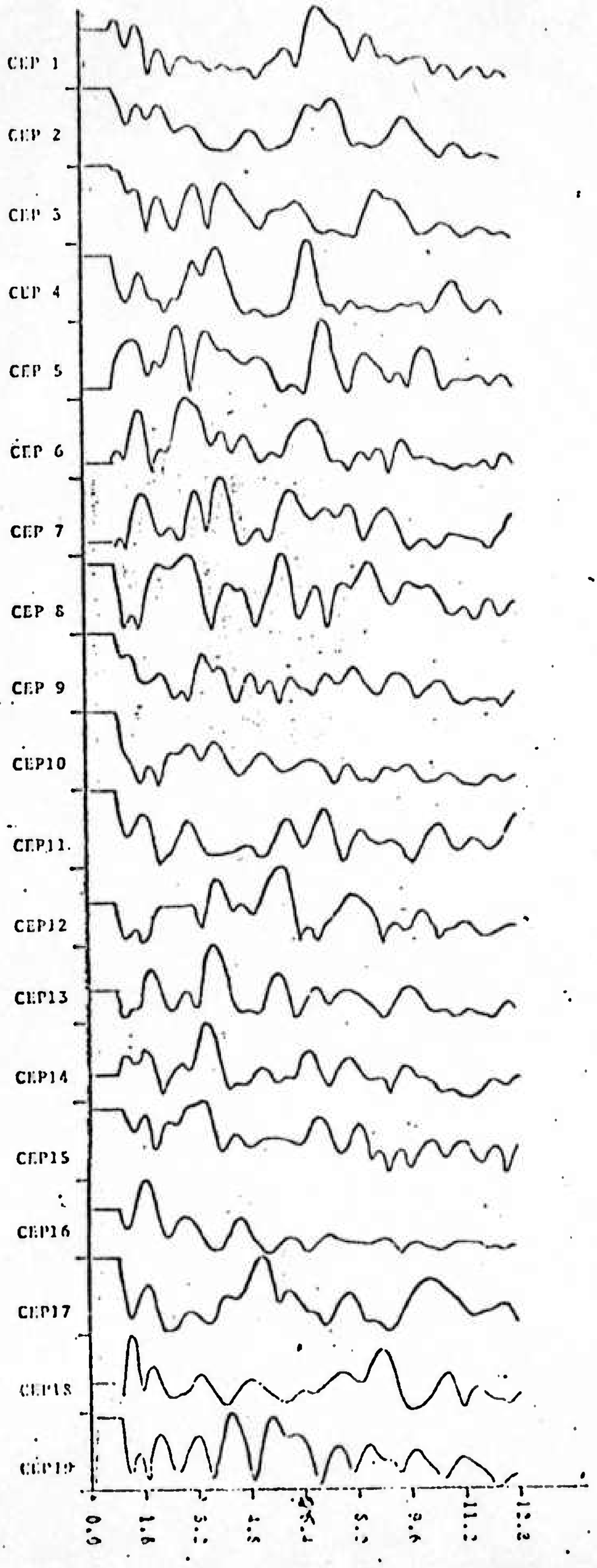


Figure 2

data analyzed. Even though it is possible to visually detect the depth phase for this event, the results of the analysis will clearly demonstrate the enhanced ability of this procedure to extract depth phase information and to determine source depths from data in which conventional analysis would fail.

In Figure 3 are the cepstrums computed from consecutive 12.8 second data samples along the coda of an individual station recording of the Illinois Event. This shows complex and changing cepstrum patterns, each containing depth phase information which the analysis procedure constructively utilizes. We will show that by using the data contained in only the later portion of the seismic coda that depth estimates can be extracted. If more depth phase information is utilized, depth estimates will be obtained for events having poorer signal/noise ratios and/or for events recorded at fewer stations. We next discuss the source depth estimate obtained using various portions of the seismic data for the Illinois Event and demonstrate that the automated analysis procedure is constructively utilizing depth phase information associated with later seismic arrivals.

In Figure 4 is plotted the cumulative CMF output versus depth computed by the automated analysis procedure for two and one half minutes of data recorded at 6 stations for the Illinois Event. The correct event depth is clearly indicated by the dominant peak at ~25 km. In Figure 5 is the same analysis except for the omission of the first minute of data. The correct depth is again indicated by a dominant peak originating from the PP, PPP and PcP seismic phases. Thus, it is possible to extract depth estimates from only data far into the coda.



Cepstra Calculated for Consecutive 12.8 Second Data Samples Along Coda (50% Sample Overlap) for Illinois Event Station WHIYK.

Figure 3

CMF OUTPUT VERSUS DEPTH USING 2 MINUTES OF DATA FOR ALL SIX STATIONS FOR ALL MODES COMBINED (ILLINOIS EVENT)

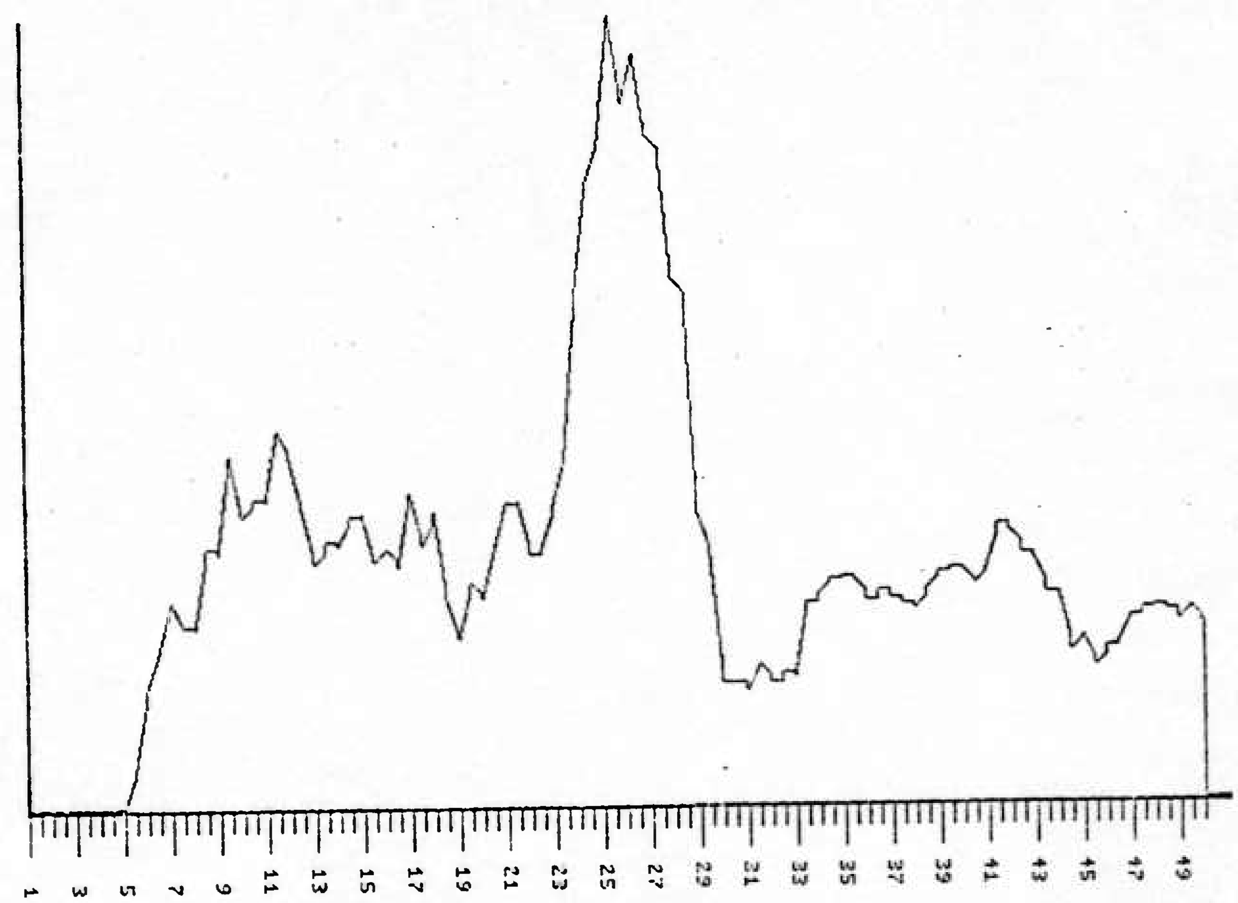


Figure 4

CMF OUTPUT VERSUS DEPTH USING THE 2ND MINUTE OF DATA
FROM ALL SIX STATIONS (ILLINOIS EVENT)

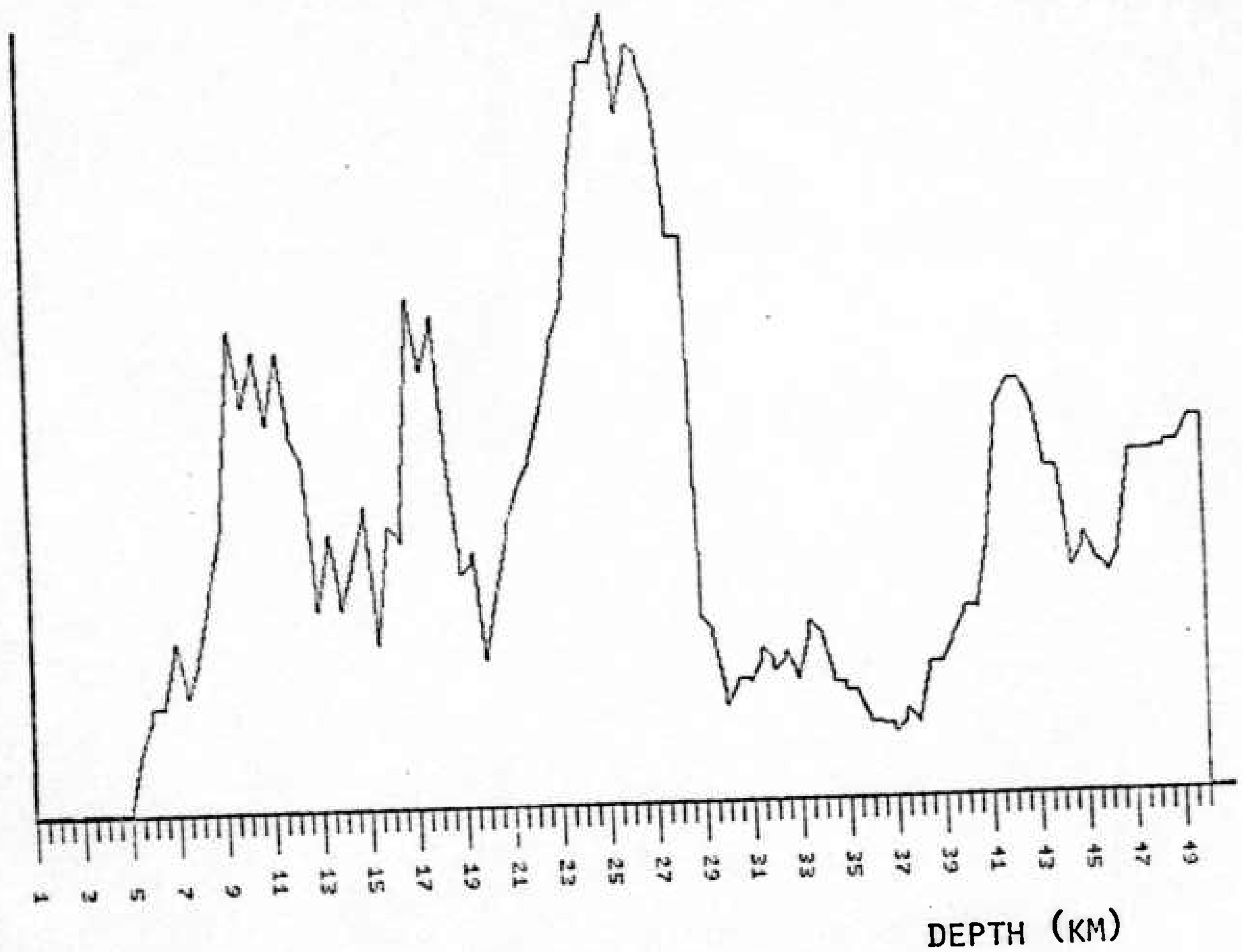


Figure 5

In Figure 6a through 6d are cumulative CMF outputs versus depth in km obtained from differential travel times associated with the individual seismic phases P, PP, PPP and PcP. In each of these cases the correct depth of ~25 km is obtained and further demonstrates the ability of this automated depth analysis procedure to extract useful depth phase information from the later seismic phases. The consistency of the stored differential travel times is indicated by the degree to which these depth estimates agree.

The ability to utilize the additional depth phase information available in the coda also enhances ones ability to obtain accurate depth estimates from fewer stations or even individual stations. This is partially due to the fact that the normal station moveout of the depth phase required to identify the depth phase occurs along the coda with the different seismic phases for a single seismogram. In Figure 7 is the cumulative CMF output versus depth for the station PGZBC which, as can be seen in Figure 2, is one station for which the depth phase is not usually apparent. A reasonable detection of the correct depth is obtained even in this case by this analysis procedure. A more typical result for the analysis of an individual station for the Illinois Event is shown in Figure 8 where a very clear detection of the event depth is obtained. The results shown in both Figures 7 and 8 cannot be obtained using a cepstrum analysis without incorporating the later phase travel times. The results discussed in this report verify the geophysical assumptions and analysis techniques which we have incorporated into this automated depth extraction procedure and there is every reason to believe that this approach will significantly increase the percentage of events for which accurate source depth estimates can be obtained.

CMF OUTPUT VERSUS DEPTH USING 2 MINUTES OF DATA FOR ALL SIX STATIONS FOR P MODE ONLY (ILLINOIS EVENT)

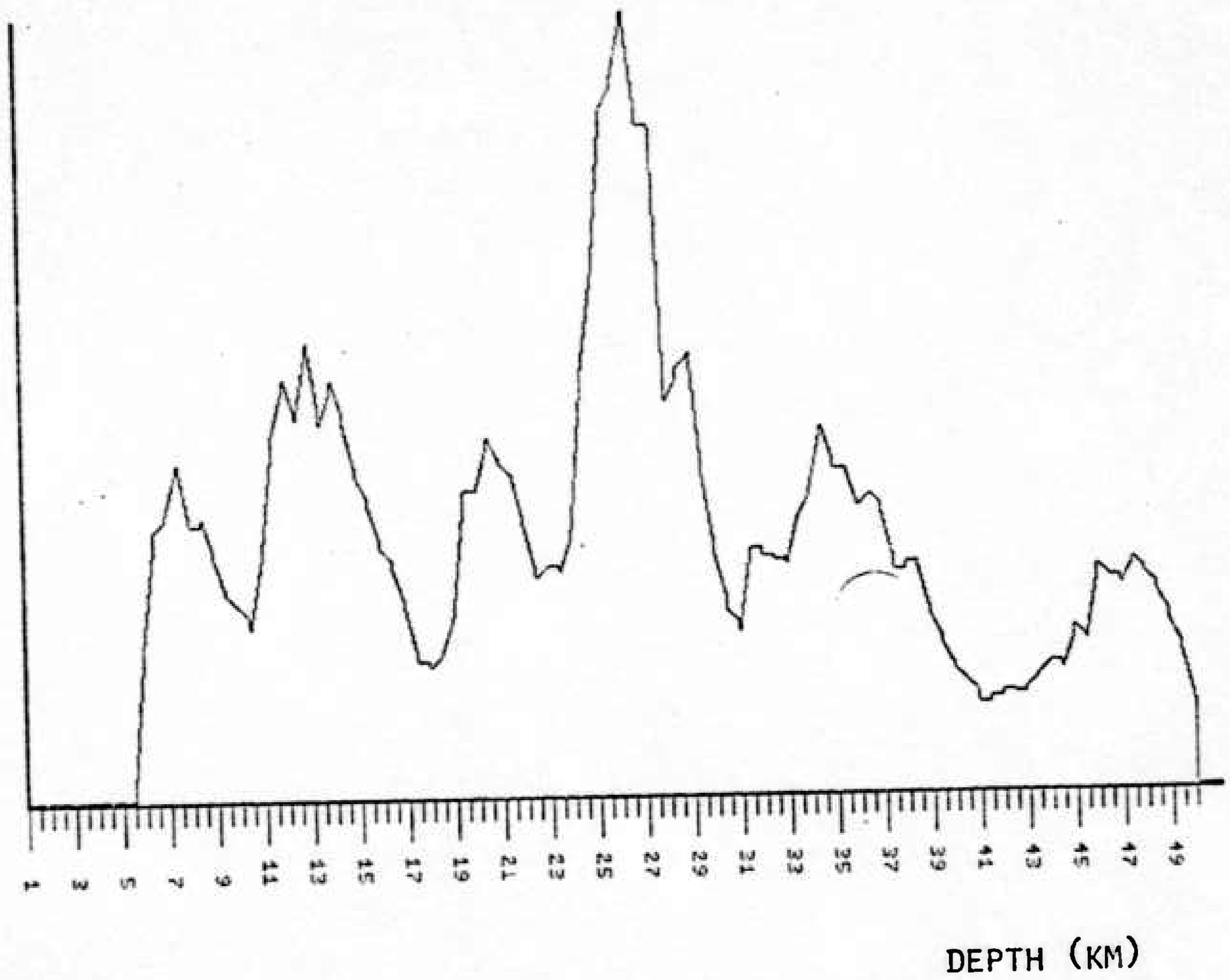


Figure 6a

CMF OUTPUT VERSUS DEPTH USING 2 MINUTES OF DATA FOR ALL SIX STATIONS FOR PP MODE ONLY (ILLINOIS EVENT)

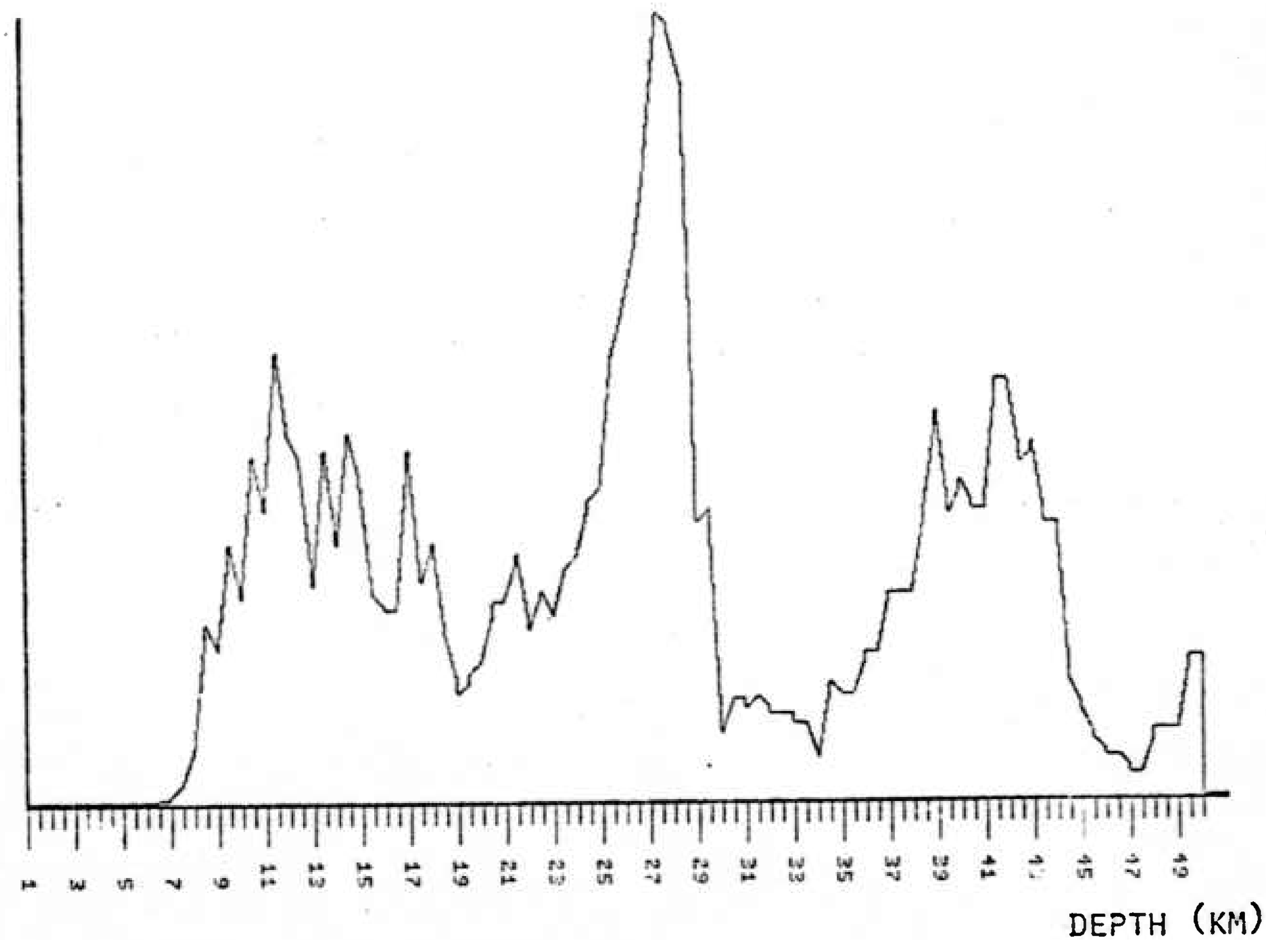


Figure 6b

CMF OUTPUT VERSUS DEPTH USING 2 MINUTES OF DATA FOR ALL SIX STATIONS FOR PPP MODE ONLY (ILLINOIS EVENT)

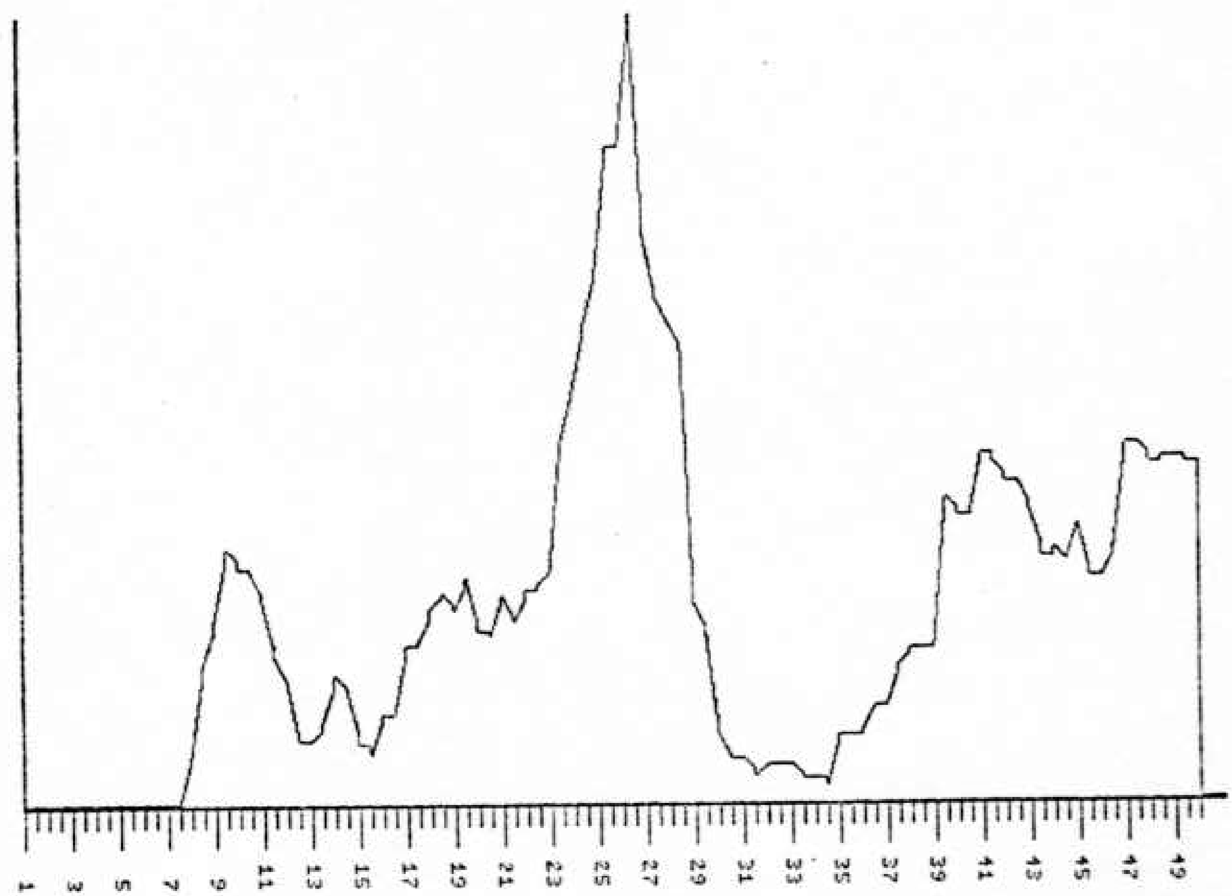


Figure 6c

CMF OUTPUT VERSUS DEPTH USING 2 MINUTES OF DATA FOR ALL SIX STATIONS FOR PcP MODE ONLY (ILLINOIS EVENT)

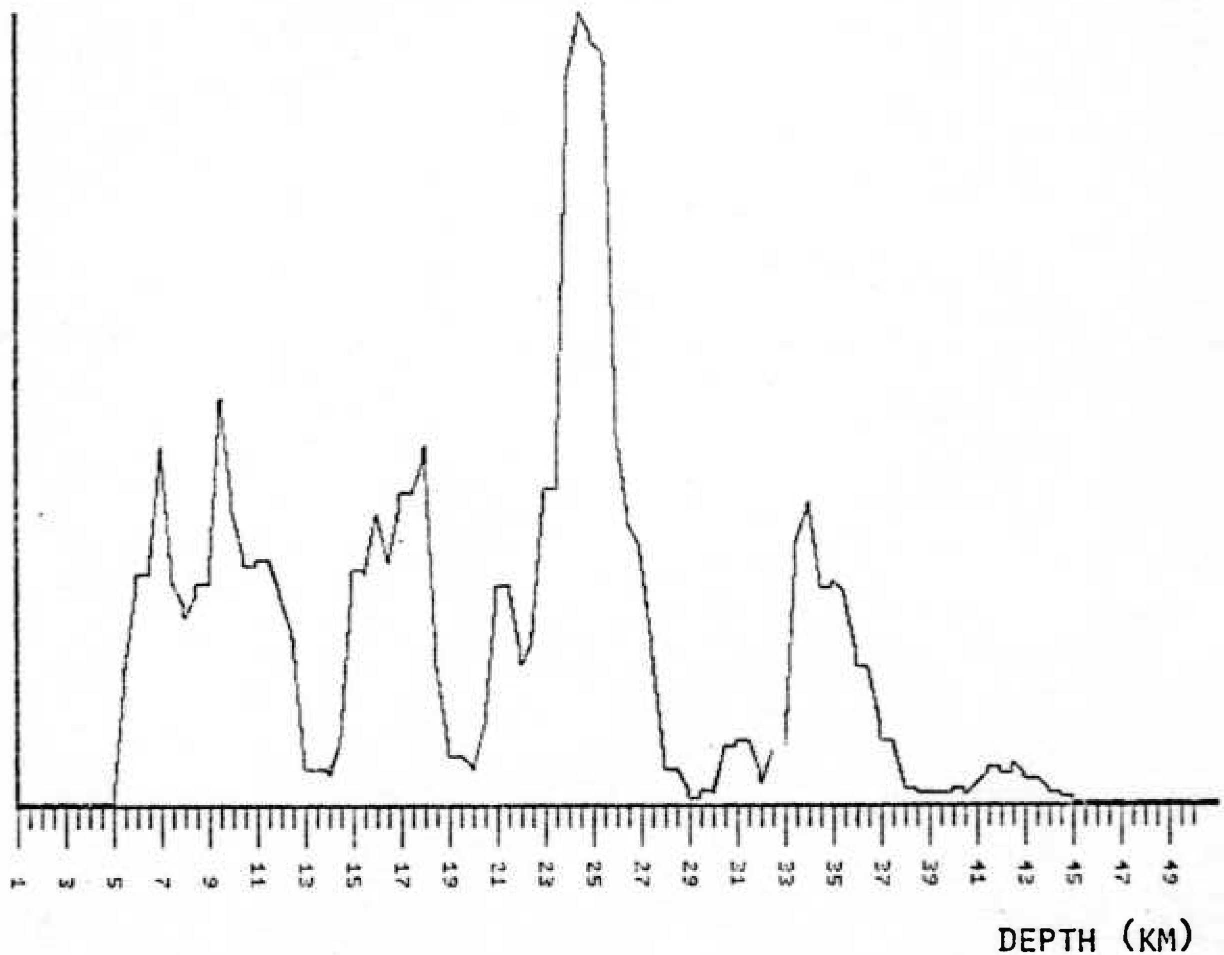


Figure 6d

CMF OUTPUT USING 1 MINUTE OF DATA FOR STATION (PGZBC)

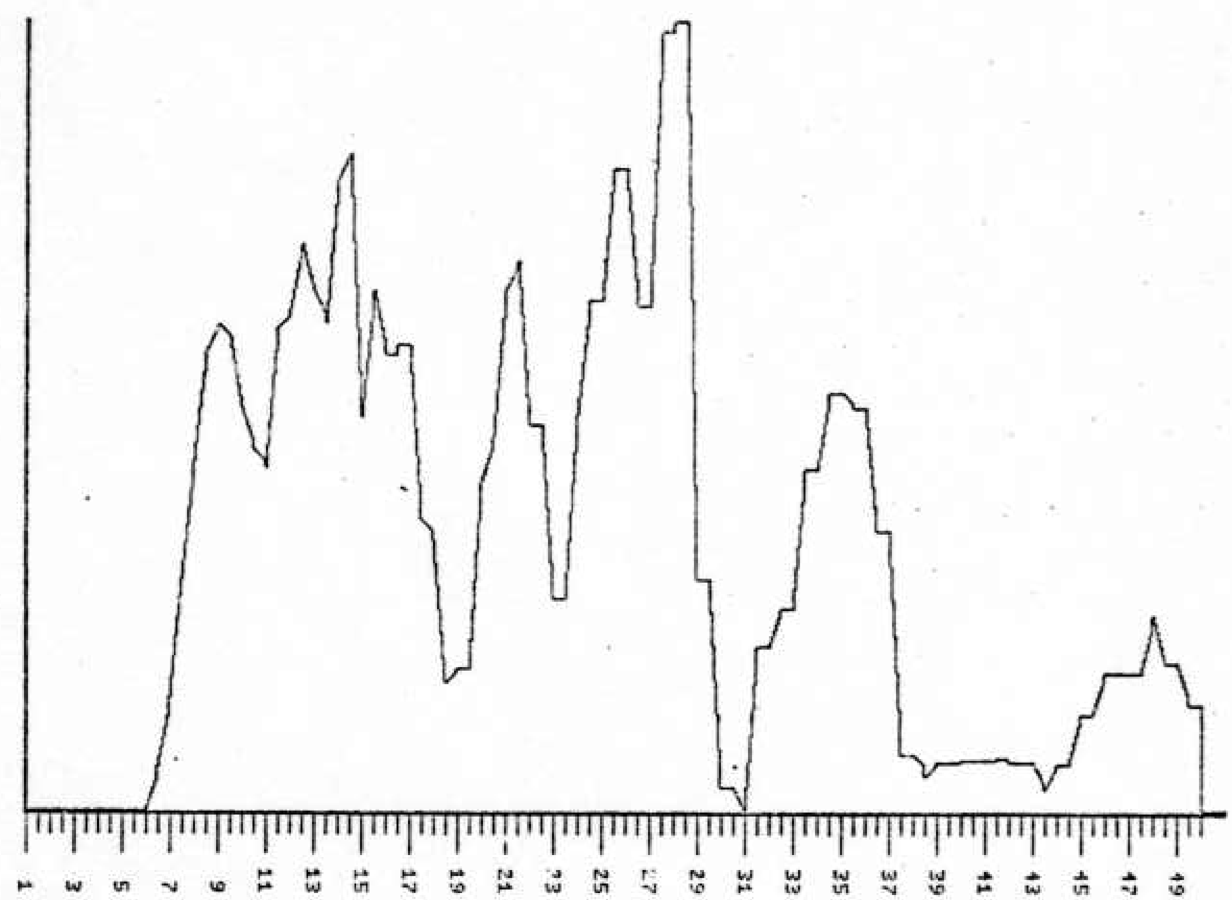


Figure 7

CMF OUTPUT USING 1 MINUTE OF DATA FOR STATION (FB-AK)

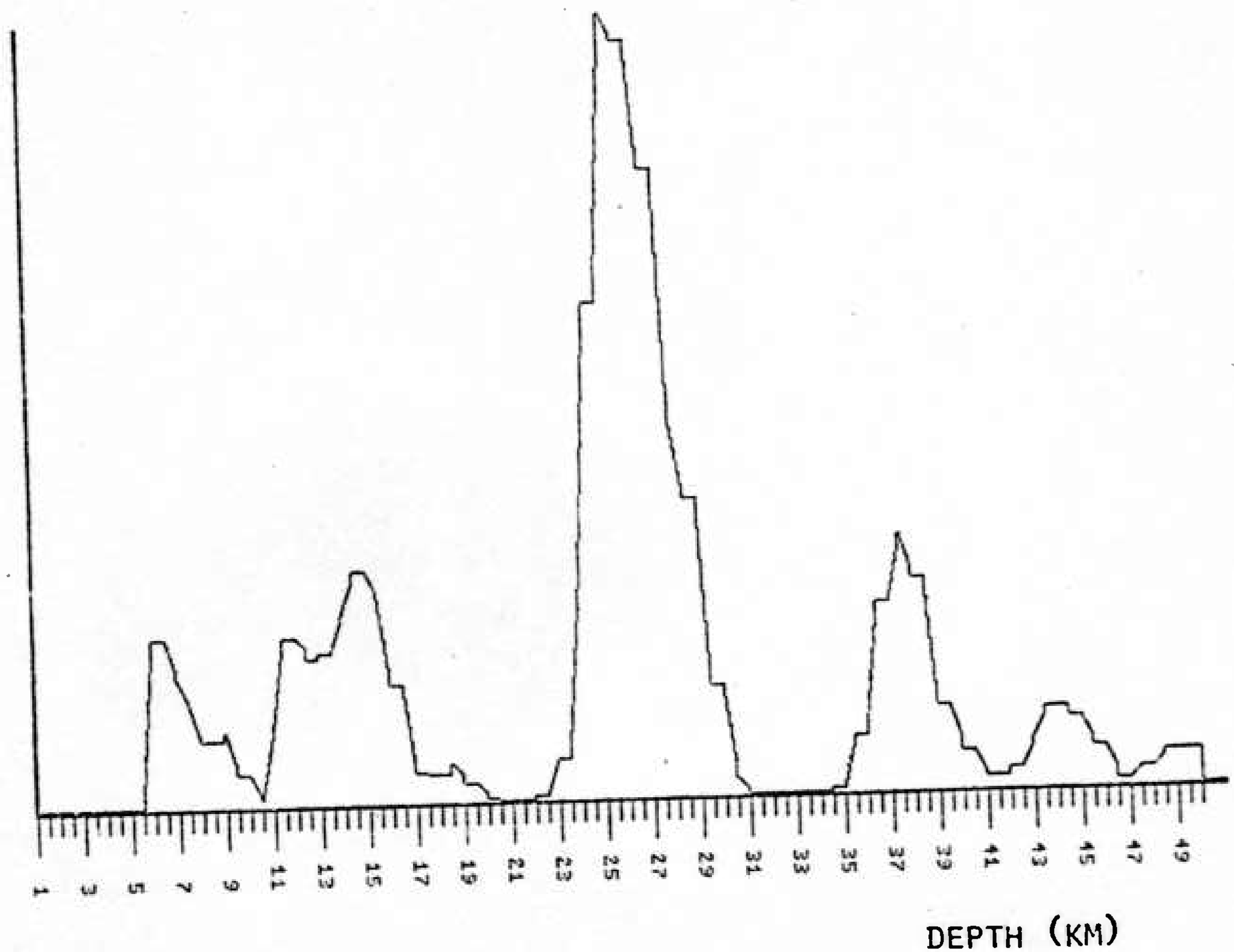


Figure 8